BUILDING ENERGY EFFICIENT SCHOOLS

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ABSTRACT

Many new school buildings consume only half the energy required by similar efficient structures designed without energy performance as a design criterion. These are comfortable and efficient while construction costs remain about the same as those for extremely inefficient buildings. To accomplish this, the school administrator must be an active participant in the design process. Energy efficient school design is a team effort involving the architect, engineer, and school administrator. This paper presents concepts and approaches to guide new school projects for energy efficiency. Comments or approaches for energy efficiency in mechanical and electrical systems are included.

THE PROCESS

Building energy efficient schools is a process involving many steps. Successful programs utilize the skills of many disciplines. Each decision made in the process should consider the influence of the specific action on building energy performance and maintenance costs, just as safety and functional aspects are evaluated. Figure 1 illustrates the variety of people involved at each event and typical time spans.

SELECTION OF A/E

Selection of the architect and engineer (A/E) is one of the most important decisions the owner or school officials will make concerning energy efficiency. Although the architect usually has the design contract with the school district, the success of a project and its energy performance depends on the entire design team, which includes the mechanical and electrical consulting engineers. Technical and professional qualifications should be the primary criteria in selecting the design team. When selecting an architect to design a new school, school officials should include the following type of questions in their interviews:

- Who are the members of the design team?
- Who is the project architect? Who is the project mechanical engineer?
- What specific energy efficiency features have you incorporated in recent school projects?
- What schools have you designed? Who was the superintendent? Who was responsible for energy efficiency?
- What type of economic analysis will be accomplished? Will trade-studies of energy efficient features be made?
- At what point in the design process will the school officials and maintenance director meet with the mechanical and electrical engineers?

EDUCATIONAL PROGRAMMING

Educational programming is critical. Without a clear definition of needs and functions from the school officials (number of students, curriculum, methods, educational philosophy, etc.), the architect will have to make certain assumptions that could ultimately affect how efficiently the new building is used. Needs should be evaluated and defined for the present, immediate future, and life of the building.

ARCHITECTURAL PROGRAMMING

Architectural programming follows educational programming and includes defining areas and relationships of various spaces, budget restrictions, and design criteria. Almost every decision made affects the energy efficeincy and consumption. During this phase, school officials have the opportunity to set attitudes and requirements for energy performance. The school officials should be concerned about energy performance rather than specific design features.

SCHEMATIC AND DESIGN DEVELOPMENT

The architect will develop schematics of the building after the architectural program is completed. Several configurations and approaches may be developed. This is the stage at which the mechanical and electrical engineers should provide input. When the various schematics are evaluated and estimated for cost, they should also be analyzed for energy efficiency. The architect and engineer working together at this preliminary and schematic stage can more effectively investigate various HVAC and lighting options. Involving the engineer at this stage permits creativity and consideration of more options. The approaches chosen can be integrated more efficiently into the architectal design of the building.

After approval for the school district of one of the schematic approaches, the architect prepares design development documents that consist of drawings and outline specifications. At this point, structural, mechanical, and electrical systems are defined. Review by the school district should include evaluation of size, orientation, space layout; educational suitability, quality, maintainability, and energy performance. Attention should be paid to zoning of air-conditioning systems, type of lighting systems, use of daylighting, control concept of air-conditioning, and complexity of systems in comparison to resident and local maintenance skills. Major changes beyond this point may result in extra cost so school officials should take time to carefully review the plans.

DEVELOPMENT OF WORKING DRAWINGS

Development of working drawings involve preparing larger scale plans, locating equipment, and working out details. School officials need to review these drawings at an intermediate stage for functional adequacy convenience, safety, and for incorporation of energy conservation features.

FINAL PLANS AND SPECIFICATIONS

This phase of the work requires very little of the school officials if early communication has been thorough and successful. The design team which includes the owner, architect, and engineer should review the plans and specifications to assure that all program requirements have been incorporated. A thorough review before release of the documents may avoid costly orders and delays during construction.

ENERGY EFFICIENT ARCHITECTURE

When considering architectural aspects for energy efficiency in new school construction, several logical questions are evident:

- How can the building be designed and oriented to rely less on mechanical and electrical systems?
- How can internal loads be reduced?
- What new technologies and techniques are available to reduce energy consumption?
- What are the best cost effective design strategies for minimizing losses through the building envelope?

In hot climates, lighting and air-conditioning account for more than half of the energy used in the average school. Therefore, the greatest architectural opportunities for achieving energy savings lie in designs that allow efficient and minimal use of mechanical and electrical systems. Examples include daylighting, natural ventilation, passive solar energy, and efficient insulation. The building envelope is an architectural feature directly related to energy performance and first cost. In hot climates, high solar load on the roof requires more attention to roof insulation and design than to the walls. Strategic use of windows and management of solar gain are required.

Site selection of schools should include input from the architect and engineer before the land is purchased. Site factors affecting energy usage include terrain, wind, and orientation. Another site factor affecting first cost and energy usage is utilities. These also should be investigated before the site is purchased. For example, a site requiring a sewage treatment plant and/or lift station results in additional first cost, energy costs, and maintenance costs.

Shape and size are architectural features that may affect energy performance. A minimum surface to volume ratio allows for the least amount of heat loss or gain from the building envelope. Therefore, designs which result in increased surface area may result in increased energy consumption. This, however, must first be evaluated in view of designs that may have more surface area but take advantage of daylighting and natural ventilation.

ENERGY PERFORMANCE AS DESIGN CRITERIA

Energy performance of school buildings is best determined or defined in terms of the annual energy consumption divided by the area of the building. Figure 2 shows a wide range of energy performance for school buildings. These site value data were obtained from energy studies of existing typical Texas public schools. All schools observed had greater energy consumption than the Department of Energy's original proposed standards for areas with climates similar to Texas. The wide variations in energy performance illustrated in Figure 2 are the result of several factors including building design, mechanical and electrical design, and operating techniques. A desirable goal for new construction would be substantially better energy performance than the average in this sampling.

ENERGY EFFICIENCY IN MECHANICAL AND ELECTRICAL SYSTEM

Energy efficient mechanical and electrical system design requires careful analysis of the education program. This is one of the first of the engineer's design task. Correlating the educational program needs to building use schedule and control are critical for energy efficient operation. HVAC systems and lighting systems must be flexible enough to provide heating, cooling, or lighting only to those spaces actually being used, if energy dollars are not to be wasted.

In conducting energy studies of more than 200 school buildings, and designing mechanical and electrical systems for more than 45 Texas school districts, we have observed, evaluated, and designed numerous types of HVAC systems. These schools and systems have a wide variation in energy performance.

Why would one elementary school have an energy consumption of 4.9 times and cost of 2.4 times of another school of similar design, use, size, and location (129,458 BTUH/sq. ft. vs. 26,000 BTUH/sq. ft.)?

The energy inefficient school had a central HVAC system employing absorption refrigeration system, multizone air handlers, and no automatic controls to turn equipment on and off. The efficient school had individual units for each zone and incorporated a simple control system to schedule on/off operations. This example represents an extreme case. We have however, observed that schools with central type systems and large multizone systems consistently have a higher energy consumption than schools with multi-unit non-central designs.

HVAC SYSTEMS

The type of school building, usage, and functions will have a great influence on the type of system or limit the choices that will be best for a specific building. For example, a building located in a hot climate, with strategically placed and limited glass, and adequate insulation will have a small space heating load. Therefore payback analysis in this case usually results in the decision to provide a low cost heating system since the heating load is small. In fact, there may be only a "warm-up" load rather than a "heating load". In areas with large fresh air and heating loads (eg. gymnasium, etc.), a central natural gas fired boiler with hot water coils in a air-handler are usually cost effective.

FIRST COST, ENERGY COST, AND MAINTENANCE SKILLS

First cost, energy cost, and maintenance skill requirements are of primary concern to the school district. These are illustrated in Figures 3, 4, and 5. These data are based on the authors' experience and observations in typical modern Texas schools. The energy cost of any HVAC system is influenced by the building structure, controls, and utility rates. Therefore the relative rankings may change slightly for various projects. Relative first cost ranking shown may vary depending on factors such as building size, shape, location, and design.

The following are conclusions that the author have derived from analyzing, designing, and observing mechanical systems in public schools.

- Individual zone type units rather than central or multizone systems cost less to purchase and install.
- Energy operating costs of individual zone split-system electric direct expansion (DX) type units have lower energy operating costs and require less skilled maintenance personnel.

ENERGY MANAGEMENT CONTROLS

Energy management controls are essential to energy efficient operations in schools. The schools with the lowest operating cost and usage that the authors have observed are those with controls to automatically schedule the on/off operation of individual split-system DX type HVAC systems. Payback of automatic energy management controls in schools with central systems is very short. For example, payback for one high school was recently observed to be less than eight months for a $17,000 control system while recent analysis on another central HVAC system project indicated a payback of 2.2 years.

Keys to successful energy management control systems in schools are simplicity of design and training of school personnel.

LIGHTING

Energy efficeint lighting design for schools includes the following:

- Use of daylighting
- Provide high pressure sodium light fixtures for outdoor lighting
- Provide metal halide light fixtures for gymnasiums
- Install energy efficient (reduced wattage) fluorescent lighting system in classrooms and offices
- Provide flexible light switching arrangements
- Utilize task lighting
- Follow recommended lighting levels

The school officials should provide input to the design team on the flexibility of lighting which permits some lights to be turned off during a significant number of school hours. For example, we have observed light levels of 300 footcandles near windows in a cafetorium. The entire row of fixtures near the windows could have been turned off without any appreciable change in light level. Other examples are turning off some lights during cleaning.

EXAMPLES

ENERGY EFFICIENT ELEMENTARY SCHOOL - WHITEHOUSE ISD

In 1979, Whitehouse I.S.D. constructed a new Elementary School with energy efficiency and maintainability as a requirement. During the 1983-84 school year, energy costs were approximately forty cents per square foot and energy performance was approximately 26,000 BTU's per square foot (site values). The school board, superintendent, selected school staff members, architect, and the consulting engineer work together as a team to develop an energy efficient school that would meet the needs of Whitehouse I.S.D. Energy efficient features incorporated in the building include the following:

- Utilization of space is efficient. All space is functional and some serve multiple purposes.
- The HVAC system is high efficiency split system heat pumps. Each classroom has individual units with thermostats in the classrooms.
- A central control system automatically turns the HVAC units on and off each day. Override timers provided are protected with a locked cover.
- Each classroom has an operable window for some natural ventilation.
- The windows are tinted to control solar gain.
- Outside make-up air is provided for kitchen hood to reduce exhaust of conditioned air.
- Daylighting is provided in the commons area which also serves as a cafeteria and auditorium. (cafetorium).
- The cafetorium also has indirect HID lighting.
- Classroom lighting is uniform and levels are approximately 70 footcandles.
- Reduced wattage energy efficient fluorescent lighting is installed in the classrooms, halls, and offices.
- High pressure sodium lighting provides illumination for the parking lot.
- Skylights providing daylighting are double-walled type to minimize heat loss and gain.
- The roof system includes a built-up roof with one inch rigid insulation. In addition, six inches of fiberglass batt insulation is installed above the lay-in ceilings.

- Vestibules are provided at the entrances.

These energy efficient features were incorporated as cost-effective energy conservation measures without any additional penalty on construction costs. Satisfied with these results, Whitehouse I.S.D. incorporated some of these same features during remodeling work at four other campuses.

ENERGY EFFICIENT ELEMENTARY SCHOOL - TATUM I.S.D.

Tatum I.S.D. opened a new modern energy efficient school on September, 1984. Many energy efficient features were incorporated into the unique school design. Team work and cooperation between the teachers, administration, architects, and consulting engineers resulted in adapting passive solar features and daylighting to create a pleasant attractive environment in a central learning center, cafetorium, multipurpose gym area, and classrooms.

Other special energy efficient features include:

- Built-up roof on one-half inches of rigid insulation. Six inches of fiberglass batt insulation is also installed above the lay-in ceilings.
- Efficient utilization of space with some areas serving multiple purposes.
- A central microprocessor control system automatically turns the HVAC system on and off.
- Energy efficient individual air-conditioning units are provided for each classroom. The thermostat is located in the classroom.
- HVAC zones having higher fresh air and heating loads are heated by a central natural gas fired boiler providing hot water to coils in the air-handlers.
- Outside make-up air is provided for the kitchen hood.
- Parking lot lighting is high pressure sodium.
- Energy efficient indoor lighting systems include indirect HID lighting in the cafetorium. The multi-purpose gym has HID lighting also.
- The windows in the classrooms are positioned for some daylighitng, but their location also prevents students from being adjacent to cold glass.
- An operable window is provided in each classroom to provide some natural ventilation.
- Skylights provided are double-walled.

During a recent site visit to the campus, physical education classes were being conducted inside the multi-purpose gym with all light fixtures turned off.

ENERGY EFFICIENT JUNIOR HIGH - PINE TREE I.S.D.

Pine Tree I.S.D.'s new 145,933 square foot junior high school had an energy performance of 28,499 BTU's per square foot (site values) and energy cost of fifty cents per square foot during the first year of operation. This demonstrates that the D.O.E. energy performance guideline of 48,000 BTU's per square foot for secondary schools in the schools geographic region is achievable and practical. Energy conservation measures incorporated to achieve the energy efficiency includes the following:

- Daylighitng in central lobby area and gymnasium.
- Vestibule at main entrance which faces south.
- Indirect HID lighting in cafeteria.
- Reduced wattage energy efficient fluorescent lighting system in classrooms and offices.
- HID (metal halide) lighting in gym with multiple keyed switching controls.
- Outdoor lighting is high pressure sodium.
- Energy efficient individual split-system heat pumps for classrooms and offices. Efficient air-duct system resulted in low fan horsepower requirements.
- A central natural gas fired boiler provides hot water for space heating in zones with high fresh air and heating loads.
- Outside make-up air is provided for the kitchen hood.
- The roof system includes a built-up roof on three inches of rigid insulation.
- Efficient utilization of space.
- Economizer cycle on gymnasium, dressing areas, and cafetorium

CONCLUSIONS

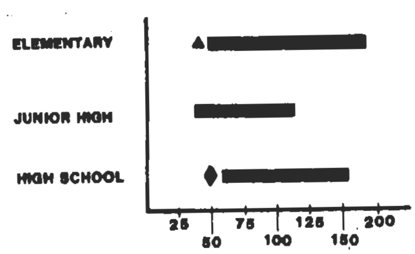
Energy efficient schools are "not an accident". They require integrated programming, planning, and design with energy performance as a priority. A coordinated team effort involving the architect, school administrators, and engineer can result in significantly reduced operating costs over the lifetime of a building.

SEQUENCE OF A BUILDING PROGRAM

	TIME TO ACCOMPLISH (months)	SUPERINTENDENT	SCHOOL BOARD	ARCHITECT/ ENGINEER	SCHOOL STAFF	COMMUNITY	BOND AGENT
1. Establish Needs	1	X	X		X		
2. Facilities Survey	1	X		X	X		
3. Educational Program	1	X	X	X	X		
4. Public Information Campaign	cont.	X	X	X	X	X	
5. Property Aquisition	-	X	X	X			
6. Architectural Program	1	X	X	X	X	X	
7. Schematic Design and Budget	1.5	X	X	X			X
8. Financial Program	1	X	X	X			
9. Bond Election	2	X	X		X	X	
10. Design Developement	1.5	X	X	X			
11. Construction Documents	3	X	X	X			
12. Advertise for Bids	1	X	X	X			
13. Award Contracts	.5	X	X	X			
14. Bond Sales	2	X	X				X
15. Construction	14	X	X	X			
16. Equipment and Furniture Installation	1	X	X	X			
17. Occupy New Facilities							

Average Time To Complete Program - 22-24 mo.

Figure 1



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EXISTING TEXAS SCHOOLS EXHIBIT
WIDE RANGE OF ENERGY PERFORMANCES

▲ ORIGINAL PROPOSED DOE ELEMENTARY SCOOL STD.
◆ ORIGINAL PROPOSED DOE SECONDARY SCHOOL STD.

FIG. 2

FIRST COST COMPARISONS
HVAC SYSTEMS
1984

System	Initial Cost Ranking (% of central chilled water system)
- Central four pipe chilled water system*	100
- Hydronic heat pump system	80
- Rooftop multi-zone units	75
- VAV-DX roof top system	75
- Split system DX w/hot water (gas) heat	70
- Roof top heat pump	65
- Roof top DX single zone	55
- Split system heat pump single zone	55
- Split system DX w/gas heat	55
- Split system DX w/electric resistance heat	33

*Includes Multi-zone, Dual Duct VAV, fan coil, and single zone systems.

Figure 3

ENERGY OPERATING COST COMPARISONS
HVAC SYSTEM

System	Cost Ranking (Most Efficient to Least)
Split system DX w/gas furnace	10
Split system DX w/ heat pump	9
Split system DX w/hot water (gas) heat	8
Split system DX w/electric resistance heat	8
Roof top heat pump single zone	8
Roof to DX single zone w/electric heat	7
Hydronic heat pump system	6
VAV-DX roof top system	6
Roof top multi-zone unit	4
Central four pipe chilled water system	4

Figure 4

MAINTINACE SKILL REQUIRED
(Highest to Lowest)

Central four pipe chilled water system
Hydronic heat pump system
Roof top multi-zone unit
VAV-DX roof top system
Split System DX w/hot water (gas) heat
Roof top heat pump
Roof top DX-single zone
Split system heat pump
Split system DX gas heat
Split system DX electric heat

Figure 5